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SUSTAINABLE HARVESTING MODEL ON FOREST PLANTATION

BY

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CERTIFICATION

I herein certify that, this work was carried out solely by Agbeko Naomi (PG 4061310) in the department of Mathematics, Institute of Distance Learning, in partial fulfillment of the requirement for the award of Master of Science Degree in Industrial Mathematics.

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Dr. F.T. Oduro Date

(Supervisor)

DECLARATION

I, Naomi Agbeko, hereby declare that this thesis "Sustainable Harvesting Model on Forest Plantation" consists entirely of my own work produced from research undertaken under supervision and that no part of it has been presented for another degree elsewhere, except for the permissible r references from the other sources, which have been duly acknowledged

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DEDICATION

I dedicate this thesis to my two lovely daughters Emmanuella Twenewaa Kuffour , Georgina Aboraa Kuffour and to my dear husband Awiti Kuffour for their love, care and support throughout the programme.

ABSTRACT

A study was conducted to develop an environmentally sound strategy for sustainable harvesting of tree crops of Begoro Forest Plantation. Its three main objectives were; firstly, to estimate current harvesting rates, secondly, to show how the biomass stock is changing in response to growth rates, harvesting rates and planting rates; and finally, using a mathematical model to predict sustainable levels of harvesting the tree crops. This study was focused on a section of the Begoro Forest Plantation. Data on planted area (compartments), tree growth, damage and harvesting were collected and analysed using Linest function Excel software. Results indicate that the total biomass of Teak and Cebrela is generally increasing with time. Using the Logistic equation, the following maximum sustainable harvesting efforts were computed: 0.38717 for Teak representing a present harvesting rate 94,700 cubic meters per year and 0.32435 for Cebrela representing a present harvesting rate 32,000 cubic meters per year. This gives a maximum sustainable harvesting effort of about 0.345 representing a present harvesting rate of about 129,000 cubic meters per year. Therefore, to ensure sustainability of the forest plantation, it is recommended that the Forestry Department should restrict harvesting to stands at rotation and thinning ages and such activities should not exceed an effort of 0.345.

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ACRRONYMS	MEANING
GSBA	Globally Significant Biodiversity Area
FSD	Forestry Services Division
SFM	Sustainable Forest Management
MTS	Modified Taungya System
FDI	Foreign Direct Investment
NFPDP	National Forest Plantation and Development Programme
NGO	Non Government Organization
ANR	Agriculture and Natural Resources
FAO	Food and Agriculture Organization
FIMP	Forestry Inventory Management Project
SRA	Social Responsibility Agreement
UNEP	United Nations Environment Programme
EU	European Union
UNDP	United Nation Development Programme
IPCC	Inventory Panel on Climate Change
OECD	Organistion For Economic Co- operation Development
UNFCCC	United Nations Frame Convection on Climate Change
IATTC	Inter American Tropical Tuna Commission
ICCAT	International Commission for the Conservation Atlantic
ICNAF	International Commission for the Northwest Atlantic Fisheries
MEY	Maximum Economic Yield

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background of the study

Ghana is richly endowed with renewable natural resources, which have played vital roles in its socio-economic development. The Colonial administration enacted legislation to control the felling of commercial tree species to protect the forest from degradation. The Forestry Department was established later to control indiscriminate felling of trees. For decades, the state has allowed timber and mining corporations free to destroy Ghana's forests. As a result, Ghana's forest cover has dwindled from 8.2 million hectares to less than 1.5 million hectares between 1900 and 1990 (www.conservation.org,) (www.biodiversityscience.org).

Between 1990 and 2005 the rate of deforestation actually accelerated to a historical high with significant forest reserves losing their entire forest cover. At currents rates commercial species could be logged out in as little as 5years Deforestation is already having a noticeable impact on water supplies, soil fertility and climate all pointing to a looming environmental disaster.

Begoro Forest District Reserve is one of the highest forest zones in Ghana. It has six reserves, namely Southern scalp, Wronbong South, Wronbong North, Atiwa and Apagya. With these six reserves, Wronbong South and Southern scarp are productive reserves, Deede and Wronbong North are Conversion Resrves and Atiwa and Apagya are under Globally Significant Biodiversity Area (GSBA) . Ghana J. Forestry, Vol. 27, (2011) Begoro Forest District Reserve has also been recognized as a nationally important reserve because the reserve provides the headwater of the river Deede. This river is the most important source of domestic and industrial water for local communities in the Begoro district. Thus, the A forest reserve protects and provides a clean water source for much of Ghana's human population and for key elements of the country's biodiversity. Ghana J. Forestry, Vol. 27, (2011)

The concept of sustainability is the capacity of someone to endure and ability to live or sustain in any opposing condition. Rosenbaum (1993) contends that sustainable means using methods, systems and materials that would not deplete resources or harm natural resources. Sustainability identifies a concept and attitude in development that looks at sites natural land, water and energy resources as integral aspect of the development Viera, (1993). Sustainability integrates natural systems with human patterns and celebrates continuity, uniqueness and place making.

Sustainable forestry often allied with "selective logging" practices. Sustainable forestry has been touted as a way to reconcile the demand for tropical woods with preservation of forests. By carefully removing only as many of the trees or other products as can be replaced relatively quickly and leaving others untouched, and, in addition, planting tree seedlings of desirable species, it is thought that forest ecosystems can be maintained so as to provide many crops of timber or other forest products. After an initial harvest, the forests would be left alone for an extended period of time, after which they could again be harvested for valuable products. In order for this system to be effective, there are several imperative preconditions: one, that the populations of organisms in the forest are able to produce a reproductive surplus; two, that there be adequate relatively undisturbed habitat; three, that soil fertility be maintained; and fourth, that erosion, runoff and road construction be kept to a minimum and sustainable management of forests reserves in Ghana, therefore the need for this study.

The primary principle of sustainable forest management requires that land be set aside exclusively for forestry purposes. In Ghana, the land has traditionally been owned collectively, with common control, management and use. Absolute ownership of land is vested in the chief (called the "stool" for his throne) or community leaders in trust for the community as a whole. The basis of land acquisition within a community, therefore, is through settlement, occupation and use by individual family members. While this tradition exists in most West African states as well, some countries, like Nigeria and Côte d'Ivoire, have brought most of their lands under state control. In Ghana, however, the creation of forest reserves as part of the nation's permanent forest estate does not change the ownership status of the land. In colonial times, Ghanaian chiefs would grant timber rights to a licensee, and this would be confirmed by the government and the courts.

Forest reserves are fully vested in the State through the Forest Ordinance of 1927, and all forest and timber resources are held in trust by the government on behalf of the stool landowners. Although landownership did not change at the time of reservation, traditional owners are denied rights of access to trees or land in reserves unless they have a permit from Forestry Services Division (FSD)

According to Asare (2000) ownership of forest is closely linked to the indigenous system of landownership. Land is communally owned and held in trust on behalf of the people through the stools and skins. Landowners exert substantial control in deciding whether an area should be set aside for reservation. The forests of Ghana are classified as forest reserves, off-reserve forests, communal forests, community plantations, private/individual plantations and institutional plantations. Although national law grants the government the authority to constitute a reserve on any land it deems appropriate, landowners must be consulted through an arbitration process that is under the jurisdiction of a reserve settlement commissioner, who must take landowners' concerns into consideration.

The establishment of forest reserves has created animosity between local communities and Forestry Services Division (FSD) because of the communities' loss of access to benefits and the perception that the reserves were created without prior consultation. Although the reservation policy has been successful in the reserves themselves, it has had a negative impact on tree and forest protection outside forest reserves. The failure of most community forest interventions can be attributed to the government failure to communicate the benefits of reservation, and the communities' notion that their land has been usurped. Communities are rarely informed of their usufruct rights, leaving the government to assume a policing role in its forest management and protection work. There have been several governments' intervention and studies on forests reserves and on how it could influence national development. These have included providing financial resources, reforestation, enacting and enforcing appropriate bye laws to achieve sustainable forests reserve management. In spite of these interventions to sustained forests reserves in Ghana, there appears to be challenges with respect to the appropriate harvests model that can be used to ensure efficient and sustainable management of forests reserves in Ghana, therefore the need for this study.

1.2 Statement of the Problem

Illegal logging has been a major issue in Begoro forest district reserve especially during the 1990s, leading to further problems with erosion throughout the area. Unsustainable exploitation of forested areas, coupled with the relatively high frequency of bush fires, has resulted in the depletion of important timber species. Despite its designations over the years as a protected area for biodiversity and watershed services, Begoro forest district reserve has been significantly impacted by humans. Intensive agriculture has led to leaching and loss of soil fertility in parts of Begoro. In some villages, deep channels have been created by surface water running over ground lacking plant cover. Trees such as Mahogany, Odum, Obeche, and Emire, which were abundant before the 1960s, are now rare. Mining activities by unlicensed individuals and groups are increasing and causing serious problems for communities. Major pollution, as a result of improper mining practices, occurs downstream from water bodies along whose banks mining takes place.

This study therefore seeks to develop a mathematical model (Harvesting Model) using differential equation (Logistic Equation) to sustain our Forest Reserves. The problem that will be addressed in this study will help prevent our Forest that has been reserved from depletion.

1.3 Objectives of the Study

The main aim of this study is to develop a mathematical Harvesting model to sustain forest reserve. In lieu of this other objectives are as follows:

1. To develop a mathematical Harvesting model using Logistic growth model.
2. To show how the biomass stock is changing in response to the growth rates, harvesting rates and planting rates.
3. To suggest suitable ranges of harvesting rates that will ensure sustainability of forest reserve.
4. To estimate current rate of harvesting the forest.
5. To assess the impacts of climate change on the livelihoods of the population.

1.4 Methodology

The Begoro forest district reserve set aside in 1926 as a way of protecting one of Ghana's only two upland evergreen forests. Begoro is a town and the capital of Fanteakwa, a district in the Eastern Region of Ghana. Begoro is about 150km north of Accra, the capital, off the road joining Koforidua and Nkawkaw. Begoro is the fifty-third most populous in Ghana, in terms of population, with a population of 29,040 people

The reserve has an amazing area of approximately 230 square kilometers and is as high as 770 meters. The Begoro forest district plant communities are classified by botanist as Upland Evergreen Forest which has 765 species of vascular plants including 106 Upper Guinea endemic species.

In this study, primary and secondary data research will be incorporated. The reason for this is to be able to provide adequate discussion for the readers that will help them to understand the issue and the different variables that involve with it. The primary data for the study will be represented by survey results that will be required from the respondents. The secondary sources of data will come from published articles from books, journals and theses and related studies. The data collected were analyzed using manual calculation and Microsoft Excel.

1.5 Justification

Institutional arrangements have been established to address the complex problems associated with forest ownership, resource tenure and their collective impacts on sustainable forest management and poverty reduction. These arrangements include using appropriate harvesting method, increased off-reserve annual allowable cuts, competitive bidding for timber rights, increased stumpage fees for timber, sharing of natural forest timber revenues, and improved incentives for Sustainable Forest Management (SFM), such as Social Responsibility Agreements (SRAs), incentives for forest plantation development, and policy reforms for ownership and resource tenure will not be able to address Sustainable Forest Management (SFM), socio-economic development and poverty reduction. This therefore, demands that, forests reserves should be supervised benefit sharing in the Modified Taungya System (MTS) and commercial forest plantations

The significance of this study is to contribute to the knowledge on harvests models as a management tool so as to help policy makers of forestry in Ghana to formulate appropriate policies in the supervision of forests reserves in Ghana. The study would provide an insight into the functions of the stakeholders as well as issues that hinder or promote their interest. Again, it would also assist the supervisory bodies such as Forest Research Institute of Ghana, Sustainable Forest Management (SFM) and (FDI) to know their areas of strength and weakness and formulate appropriate policies to reinforce them.

1.6 Organization of the study

The study would be structured into five chapters. Chapter one would be the introduction of the study. In this chapter, issues such as the background of the study, problem statement, objectives and the significance of the study would be discussed. This would help situate the research in its proper domain and facilitate the easy understanding of the chapters. Chapter Two would be the discussion of related literature and theoretical concepts that underpin the study Mathematical models would be discussed in Chapter three. This would include discussion of population growth models, research design and methods as well as data analysis plan. The fourth chapter would contain the analysis, presentation, and discussion of the data gathered from the field. In this chapter, the findings of the study would be discussed. Also, appropriate statistical analysis and data presentation tools would be used to indicate the findings in this chapter. Chapter Five would contain the summary, conclusion and recommendation of the major findings in terms of objectives of the study.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

In this chapter we present works carried out by other scholars in the field of sustainable forest management and sustainability harvest model of Forest Reserve.

2.1 ESTABLISMENT OF FOREST RESERVE IN GHANA

2.1.1 The State of Ghana's Forest

At the beginning of the twentieth century, the forest area of Ghana covered about 34 percent of the total land area. Forest reservation was started in 1927 by the colonial administration and ensured the reservation of 11 percent of the country's total land area. In all, 282 forest reserves and 15 wildlife protected areas, occupying more than 38,000 km^2 or about 16 percent of the total land area, were established and gazetted in Ghana. There was an additional 4000 km^2 of forest outside this gazetted area. The main aim of the reservation programme was to ensure the protection of substantial areas of forest, but the process of forest land reservation ignored the traditional tenure system, which led to a negative attitude to reserves among the population, especially in forest fringe communities. This situation was aggravated by a failure to inform forest communities of their usufruct rights and by the focusing of forest management on forest protection by the central Government. Collaborative Forest Resource Management Workshop held at Akosombo, (2007)

All forest lands in Ghana are held in trust by the government, which manages them for the stool landowners. The Forest and Wildlife Policy of 1948 stipulated that the government manage forest resources single-handedly, without the collaboration of forest fringe communities, and did not yield many positive results. Passage of the current Forest and Wildlife Policy of 1994 led to some progress regarding stakeholder collaboration, but did not solve the ownership issue regarding trees outside forest reserves and on farmland; the lack of clear ownership status calls for a policy review. The policy of 1948 was driven by the need for commercial timber production, mainly for export. The 1994 policy, on the other hand, aims at the conservation and sustainable development of the nation's forest and wildlife resources for the maintenance of environmental quality and a steady flow of optimum benefits to all segments of society. The forest sector's potential to contribute to Sustainable Forest Management (SFM) and poverty reduction for socio-economic development faces challenges related to forest ownership, resource tenure and the lack of effective participation from resource owners and local communities in forest management decision-making. This lack of participation is due to inadequate incentive structures to ensure Sustainable Forest Management. National Forest Plantation and Development Programme,(NFPDP),(2001)

In Ghana, forest ownership is derived from the system of land inheritance. There are two forms of inheritance: the patrilineal system and the matrilineal system. As a result of the different historical settings of these two systems, they have different concepts of land, land acquisition and landownership. Under the patrilineal system, inheritance passes directly down the male line, while in the matrilineal system succession to property and land passes along the matrilineal line according to primogeniture in the following order: brothers, sisters' sons, sisters, and sisters' daughters. Agyeman, (1991). These systems of land inheritance do not necessarily include tree tenure rights, so SFM is difficult to establish in

Ghana. Reform of tenure systems would help to ensure the long-term growth of not only sustainable forestry development but also the national economy as a whole.

2.1.2 Standard of living of Forest-fringed Communities

A presentation made by Katako and Vigoda (2007) reiterated that about 70% of Ghana's population live in the rural areas and depend on natural resources for their livelihood. The impact of extractive industries and poor agricultural planning has been that the only remaining viable forest is in state managed reserves. A combination of official policy and insensitive administration prevents forest fringe communities from accessing these resources legally for livelihood purposes though the extractive industry still has unfettered access. Poverty continues to deepen in forest fringed communities despite enormous potential for improving their livelihoods. Non Government Organization (NGO) and donor inspired initiatives to alleviate poverty have not achieved the desired impact because these efforts have not addressed the underlying questions of governance, community participation in decision making, ownership, benefit from and responsibility for sustainable resource management. Farmers' lack of incentive to conserve forest resources on their farmlands exacerbates the drastic loss of forest cover. The trend of forest exploitation and logging activities in the last 15 years and the pressure to mine forest reserves for gold, bauxite and diamond call for a drastic intervention if Ghana is to have any forest left in the very near future.

2.2 NON GOVERNMENT'S INTERVENTION IN FOREST RESERVES MANAGEMENT

2.2.1 CARE Ghana Agriculture and Natural Resources (ANR) Programme

The purpose of CARE Ghana's and Natural Resources programme is to contribute to poverty reduction in Ghana through Sustainable livelihoods for poor and marginalized rural families who depend primarily upon natural resources. The project realized that if sustainable change was to take place it would not be only through service delivery, but also required shifts in the policy and practice of government and a more favourable policy and legal framework to enable the poor to lift themselves out of poverty.

CARE Ghana's involvement with communities on sustainable forest management and land use practices began in 1999 with a CARE Denmark-funded project where 600 farm families were supported to improve their livelihood via access to forest resources, in return for taking responsibilities for the growth and sustainable management of their resources. The key approach was to facilitate community-based forest resource management system, while farmers are interested in diversifying their farming activities beyond cocoa to broader farm-forest systems1, they faced challenges which would continue to entrench forest fringe communities in poverty unless addressed. These challenges included the denial of commercial access to high value forest resources to improve their livelihoods and exclusion from the governance processes that would enable benefit sharing from forest resources and decision making on forest resource governance and management. Katako and Vigoda (2007)

2.3 Forest Protection

The forest protection problem in Ghana is multifaceted. Preferred commercial species have attracted intensive logging in the semi-deciduous zone, a sensitive environment under threat of desertification. Also, illicit logging increased to take advantage of the Forestry Department's incapability in checking timber felling and ensuring concessionaires' compliance with prescriptions. Food and Agriculture Organization (FAO) (1999) identified these problems:

- Slashing and burning of forest and grassland is part of the traditional bush fallow cultivation. Usually, the long fallow would allow enough vegetal cover to develop. However, increasing population growth over the last two decades has not only shortened the fallow period but also increased demand for land. Increased cash cropping, urbanization and development have compounded such a demand.
- Bush burning has been the cause of most forest degradation in the moist semi-deciduous zones. Pioneer trees of little economic merit dominate burned forests and are more prone to fires in the future. Fire could be the greatest threat to the long-term survival of the forested area in Ghana.

Mining and quarrying, especially by small-scale operators, and large-scale mining of bauxite, manganese and gold pose serious threats to forests in the High Forest Zone. FIMP (1994). Because of these impacts, the Forestry Department embarked on a forest protection strategy in 1994, aimed at protecting the diversity, quality and sustainability of the forest estate. "Fine-grained protection" as a strategic tool applies to all forest uses, including harvesting, plantation development, farming and mining. The tactic ensures that such disturbances take place only after careful environmental impact evaluation. Fine-grained measures aim at keeping the integrity of the forest ecosystem and its biological content to ensure endemic status of species. “Large-grained protection” forbids disturbance in whole blocks of forests to ensure environmental stability and biodiversity conservation. Richards (1995).

2.4 FOREST RESERVES

Forest reserves are fully vested in the State, through the Forest Ordinance of 1927, and all forest and timber resources are held in trust by the government on behalf of the stool landowners. Although landownership did not change at the time of reservation, traditional owners are denied rights of access to trees or land in the reserves unless they have a permit from Forestry Services Department. Since its outset, this law has created animosity between local communities and Forestry Services Department, because of foregone benefits and the view that reserves were created without consultation. The management of trees within forest reserves, and the rights to own, plant, use and dispose of them are controlled by the State through the Forest Protection Decree of 1974.

According to Asare (2000), ownership of forest is closely linked to the indigenous system of landownership. Land is communally owned and held in trust on behalf of the people through the stools and skins. Landowners exert substantial control in deciding whether an area should be set aside for reservation. Although national law grants the government the authority to constitute a reserve on any land it deems appropriate, landowners must be consulted through an arbitration process that is under the jurisdiction of a reserve settlement commissioner, who must take landowners' concerns into consideration. Some proposed reserves have had to be abandoned because of strong opposition from landowners.

Again Asare (2000) reported that in some instances, such as wildlife reserves, the government purchases the land outright from the landowners, thereby becoming the property owner and enjoying the same rights as any other landowner. In effect landowners, - whether stools, skins, the government or individuals – wield immense power on the setting aside of an area as permanent forest estate, and always have rights to revenue from the exploitation of the resource.

2.5 TYPES OF FOREST RESERVE

2.5.1 Communal forests

Communal forests are woodlands outside forest reserves; most of them are in northern Ghana. Unlike the off- reserve forests of the south, which have economically exploitable timber trees, the trees in communal forests can be used only by households as sources of fruits, other foods, medicines etc. Communal forests are either natural or established by communities with support from Forest Service Division (FSD) and Non Government Organisation (NGO). Trees in these forests cannot be owned or inherited by individuals, but usufruct rights − such as collection of herbs, fuel and food can be, according to the relevant rules and regulations. In Upper West region for instance, some communities have reserved areas of land for fuel wood production. NFPDP Annual Report, (2005)

2.5.2 Sacred groves

According to Ghana's Environmental Protection Agency (2005), sacred groves are forests that communities have reserved on communal land. They occur throughout Ghana and are usually very small in size. No individual has the right to plant, use or inherit trees and other tree products in most of the she traditional forest groves, which are of great socio-cultural and religious significance. The rich histories of these natural enclaves are diverse, but most are related to the beliefs and values of local people. Traditional authorities employ indigenous strategies to exclude human activities from sacred groves, retaining them in or near their original natural state. The most common of these strategies are taboos that restrict people's entry altogether or on particular days. Sacred groves therefore present a mosaic of undisturbed habitats for flora and fauna within degraded ecosystems.

2.5.3 The Taungya system

Amanor,(1996) , suggested that Taungya is a system of forest plantation in which small-scale farmers are allowed to cultivate crops between the seedlings of a forest plantation for the first few years after planting The system was introduced in 1928 to restore Ghana's forest cover, solve the land shortage problems for farmers living near forest reserves, and provide the Forestry Department with labour for plantation development. Since then, lack of ownership rights to trees planted on reserved land have proved to be a great disincentive for Sustainable Forest Management (SFM), and the Taungya system has been modified. The Modified Taungya System includes benefit sharing and recognizes farmers' tenure rights. It is expected to promote Sustainable Forest Management and poverty reduction approaches in Ghana. The Modified Taungya System puts into action the 1994 Forest and

Wildlife Policy's concept of granting individual farmers and tree growers the right to plant and inherit trees in forest reserves.

2.5.4 Off-reserve forests

Ownership rights to economic timber trees in off-reserve forests also rest with the government, but access to other forest and tree resources depends on the prevailing landownership and inheritance system. Generally, tree resources are allocated to satisfy the increasing domestic and fuel wood demands. The greater a tree's economic value, the greater the restrictions placed on its use by landowners, especially for tenants and immigrants. It is difficult for immigrants to own trees through planting on the land they rent. Such tenure restrictions reduce tenant farmers' attachment to their farmlands and are major disincentives to Sustainable Forest Management and poverty reduction. Land tenure rights and land administration have to be fully reviewed so that their contributions to both local and national economies can be increased through Sustainable Forest Management and poverty eradication.

According to Opoku (2005), the 2002 revision of off-reserve royalty rates had had very poor results. He states that the formula for distributing royalties from stool land was set out in the constitution, so by seeking to determine royalty rates administratively, the government is violating the constitution. He also comments that the Forestry Commission's collection of stumpage has been so poor that the benefits of the policy have been nullified.

2.5.5 Traditional, community and private forests

Asare (2000), opined that Traditional authorities employed indigenous strategies to prevent human activities from encroaching on sacred groves. The influences of Western culture, Christianity, education and their attendant modernization have eroded many of the basic tenets underpinning the survival of traditional reserves. Rising population, coupled with increased demand for agricultural land and infrastructure have also led to serious encroachment of some sacred groves. Although some groves are well-preserved with few or no signs of degradation, others have been seriously affected by farming activities, unauthorized logging, bushfires, housing development, hunting and gathering expeditions, road construction, and mining. Some groves have been degraded beyond recovery as a result of encroachment. Local communities and Non Government Organizations have initiated rehabilitation programmers' in some groves, but a major setback to the management and monitoring of sacred groves is the lack of data with which to elicit support from interested groups. If they are well managed, some of the sacred groves that have survived in permanently protected forest reserves could provide benefits such as genetic material for research, and environmental improvement through microclimatic effects. At present, however, sacred groves are not being properly managed and have only a minimal effect on poverty reduction.

2.6 MANAGEMENT AND HARVESTING OF TREES AND FORESTS

The following analysis of which tenure category works best focuses on resource management by the Forestry Commission. Laws lay down the procedures for harvesting and disposing of the resources under Forestry Commission Authority, but do not define proper management practice. The technical conditions prescribed for proper harvesting and the additional requirements expected of timber right holders can be said to sum up the conditions that ensure Sustainable Forest Management and poverty reduction through the flow of benefits to forest fringe communities.

This case study focuses on the additional requirements expected of timber right holders, which include

- a Social Responsibility Agreement (SRA);
- A reforestation plan
- Social amenities;
- Specifications of timber operations.

A Social Responsibility Authority has to be settled between the holder of a Timber Utilisation Contract and the community that owns the land or forest. According to the logging manual, the Social Responsibility Agreement should contain a code of conduct requiring the Timber Utilisation Contract holder to respect the rights of the landowning communities with respect to farming operations, Non Wood Forest Products and revenue from harvesting. Other rights and obligations can be added as appropriate. The regulation stipulates that the reforestation or aforestation plan must provide at least 10 hectares of forestation for each square kilometer of contract area (i.e., 10 percent of the area allocated). It does not mention where such forestation should take place. The Timber Utilisation Contract holder must provide social amenities to the inhabitants of the contract area, the cost of which should not exceed 5 percent of the annual royalty accruing from operations under the Timber Utilisation Contract. The Timber Utilisation Contract holder also has to agree with the landowning communities the timber operational specifications, which might include obliging the Timber Utilisation Contract -holder to provide a certain amount of off-cuts for community use, employment, financial support, etc. Timber Industry Development Division Annual Report, (2005)

The technical conditions for proper harvesting prescribe that no harvesting is permitted without a Timber Utilisation Contract; this means that even the person who planted and maintained the trees cannot harvest them for commercial purposes without a Timber Utilisation Contract. Timber Utilisation Contracts outside forest reserves cannot be granted without the written permission of the landowner on whose land the forest plantation or timber stands. If the landowner does not give permission, a committee should consider whether he/she is justified and should then submit a report to the regional forestry manager with the comments and recommendations of the district manager. If neither the landowner's permission nor a committee report can be obtained, the Timber Utilisation Contract cannot be granted. The amendment act has removed this class of forest tenure from Timber Utilisation Contract allocation procedures. While the Timber Utilisation Contract applies to all the trees in a stipulated area, a Timber Utilisation Contract allows the harvesting of only a specified number of trees. A Timber Utilisation Contract can be granted to a community, town committee, rural community group or Non Government Organisation to harvest a number of trees for social and community purposes from areas that are not under Timber Utilisation Contracts .Timber Industry Development Division Annual Report,(2005)

2.7 Harvesting Practices

A silviculture system covers all management activities related to growing forests - from early planning through harvesting, replanting and tending the new forest. Ghana's diverse forests are generally managed under one or a blend of three silvicultural systems:

- The clear-cut system removes most of the trees from an area, with patches of trees and buffers left to protect other values.
- The shelter wood system harvests trees in stages over a short period of time so the new forest grows under the shelter of the existing trees.

The selection system removes timber as single trees or in small groups at relatively short intervals, repeated indefinitely. This is done carefully to protect the quality and value of the forest area. . Forest managers consider a variety of ecological, economic and social factors when choosing a silviculture system. Silvicultural systems meet the unique needs of each forest site. The clear-cut and shelter wood systems are used to manage even-aged forests, which are defined by relatively small age differences between individual trees.

According to Brown (1934) clear cutting of trees was the general harvesting method on private land. Clear cutting of trees is generally the most ecologically appropriate way to harvest and renew the boreal forest because it most closely resembles the large natural disturbances, such as fire, wind, floods and insects, which are common in the region. Boreal tree species germinate and grow best in full sunlight, resulting in natural, pure stands of trees of the same age. The selection system is used to manage uneven-aged stands, which means the forest has trees in various stages of development, it is appropriate for species that thrive in shade such as western red cedar and sugar maple.

He also commented that traditional practices were generally "based upon immediate profits and the exploitation of the forest with little or no thought to the future." He cited the disadvantages of selective logging as: there was no marked advantage in cutting only the largest trees for some products (cross ties, poles, etc.); more care was needed to remove the timber; the immature timber had to be protected and taxes paid on it; it was not useful in even-aged forests or dense forests; and it could not be practiced in areas cut under enforced liquidation of standing timber assets. Heavy taxation encouraged liquidation of standing timber assets.

2.7.1 Harvesting Effects

Harvesting methods vary in degree of disturbance. On steeper slopes (generally >35% slope), helicopter, skyline, or ground cable logging systems are common. Trees may be felled and removed with full suspension of logs via a helicopter or cable system and carried to landing sites. With a ground cable system, one end of the log is suspended and the other end is slid on the ground to a landing area. On less steep slopes (generally <35% slope), wheeled or tracked forwarders or skidders remove felled trees. A forwarder loads and carries trees to a landing area in one operation. A skidder drags the logs to the landing generally on designated skid trails. Skid trails cause the most disturbances by displacing the ground cover and compacting the mineral soil. Additional disturbance is caused by skidder tires loosening the soil, especially on slopes over 20%.

Tree cutting by itself does not cause significant erosion, and timber harvest operations usually cause less erosion per unit area than roads, but the area of timber harvest is usually large relative to roads so that the total erosion from timber harvest operations may approach that from roads Megahan,(1986). However, the decrease in the number of trees results in a decrease in evapotranspiration, which contributes to increased subsurface flow, stream flow, and channel erosion. Field research has found that timber harvesting tends to compact the soil. Compaction increases soil erosion and adversely impacts forest productivity. Yoho, (1980). Most erosion comes from skid trails on timber harvest units because of the reduced infiltration rates and disturbance to the organic layer. Robichaud et al, (1993b). Therefore, the accelerated erosion caused by timber harvesting may result in deterioration of soil physical properties, nutrient loss, and degraded stream water quality from sediment, herbicides, and plant nutrients Douglas and Goodwin, (1988).

2.8 MODELS FOR FORESTS RESERVATION

2.8.1 Percentile-based Models for Plantations

Clutter and Allison's (1974) model for P. radiata plantations in New Zealand divides the stand into 25 cohorts, each initially with an equal number of trees. The median diameter for each cohort is derived by fitting a Weibull function to the diameter distribution of the whole stand, and computing the diameters corresponding to the second, sixth, . . ., 98th percentiles. Growth estimates are based on this hypothetical median tree for each cohort. The model assumes that 1there is no mortality, and that trees do not change ranking, so that median trees continue to represent their cohort throughout the projection, unless thinning is simulated. The size distribution for the stand can be reconstructed at any time during simulations by fitting a Weibull distribution to the 25 hypothetical trees. Alder's (1979) model for coniferous plantations in east Africa uses deciles, and models the development of the ten median trees corresponding to the fifth, 15th, . . ., 95th percentiles of the cumulative tree size distribution. The initial size distribution is estimated using a Weibull distribution, when the stand attains a dominant height of seven meters. The model is concerned primarily with growth after this height has been attained. Diameter increment is predicted from estimates of height increment derived from height–age curves. It is assumed that there is no mortality, so that no record of trees in each cohort is maintained: it remains constant at ten percent of the total stand stocking. All trees in each cohort are assumed to be identical to the median tree, and no attempt is made to reconstruct a diameter distribution. Both these models have been used operationally in making predictions for commercial plantation management. These methods may be efficient for even-aged stands, but care is needed in choosing the representative trees. In uneven-aged stands, most of the trees may have small diameters, but the few large trees may be of considerable importance in terms of stand dynamics and commercial value. In such stands, it seems inefficient to form cohorts with equal numbers of trees, and alternatives should be considered.

2.8.2 Cohort Models for Mixed Stands

In mixed stands, the formation of cohorts may be determined by species and other attributes, instead of computational niceties such as equal numbers of trees. Many attributes may be used to form cohorts. Species, size, vigour (e.g. crown illumination) and commercial characteristics (e.g. stem straightness) are all obvious candidates for forest management models, but other factors may also be accommodated. Reed's (1980) succession model forms cohorts from trees of the same species with similar age, height, diameter, leaf biomass, etc. Trees remain in their initial cohort throughout simulation, unless damaged by browsing which initiates a new cohort for the damaged stems.

Leary's (1979) model allowed varying levels of resolution. At the lowest level of resolution, it uses a single cohort for each species. At the intermediate level, it simulates three cohorts for each species. At its highest level of resolution, each cohort represents an individual tree and the model becomes a tree list model thus the user can select a level of resolution appropriate to his requirements and budget. The model predicts the sum of diameter increments for each cohort, by estimating the potential diameter increment of the mean tree in each cohort (Hahn and Leary 1979), adjusting this for stand density and competition Leary and Holdaway (1979), and multiplying by the number of trees in the cohort. The list of individual diameters input to the model is not discarded, but is retained and at the end of the simulation each tree is updated by its share of the accumulated increment in its cohort Leary et al. (1979*b*). This allows better estimates of final tree sizes. Vanclay (1989*a*) described a cohort model which was an early prototype of the NORM model. For efficient simulation, species were grouped according to growth habit, size at maturity and harvesting guidelines. Preston and Vanclay, (1988). Species groups were coded so that the appropriate growth (5 groups) and harvesting group (9 groups) could be wood processing industry, secure in the knowledge that the forest will not be over-exploited.

2.8.3 State Space Models

García (1984, 1994) used a state space approach to model plantations. The stand is represented by a few state variables; usually stand basal area, number of trees per hectare and top height. It is assumed that these state variables summarize the historical events affecting the future development of the stand, and thus that future states can be determined by the current state and future actions, and that other variables of interest, such as volume, can be derived from these state variables. This assumption is critical to this and several other modeling approaches and requires that two conditions be satisfied. The state variables must adequately describe the composition and structure of a forest stand, and should reflect all past silvicultural events, so that growth predictions do not need estimates of stand age, time since thinning, etc. These assumptions imply that growth predictions can be made simply by updating these few state variables.

2.9 Climate Change

Climate change is arguably the greatest contemporary threat to forest ecosystems, biodiversity and livelihood of poor forest fringe communities. It is one of the greatest environmental, social and economic threats the world has ever faced. UNEP, (2009) EU, (2009); OECD,(2008); IPCC, (2007); UNFCCC, (2006). It is real and happening faster than we previously thought with serious devastating impacts in developing countries, particularly on the Africa continent. UNEP,(2005); EU,(2009); IPCC, (2001). The poor countries in particular are the most vulnerable because of their high dependence on natural resources and their limited capacity to adapt to a changing climate WRI,(2005); UNEP, (2005); Desanker, (2002); FAO, (2005); IPCC, (2001). These impacts are expected to deepen poverty, food insecurity, poor livelihoods, desfunction of infrastructural facilities, environmental resources and unsustainable development. FAO, (2005); IPCC, (2001).

According to Denton et al.(2001) vulnerability and adaptation to the adverse impacts of climate change are among the most crucial concerns of many developing countries, especially the Sahelian countries. The main cause of climate change is the rising concentration of greenhouse gases (GHGs) in the atmosphere, which stem primarily from both natural and human activities. IPCC,(2007). The main GHGs are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), principally from the burning of fossil fuels, forest destruction and agriculture and Chloro fluorocarbons, (CFCs) used in air conditioners and many industrial processes. Africa's vulnerability to climate change is being exacerbated by a number of non-climatic factors, including endemic poverty, hunger, high prevalence of disease, chronic conflicts, low levels of development and low adaptive capacity.

2.9.1 Impacts of Climate Change

The impacts of climate change are often specific to individual sectors or regions, thus making some sectors and regions more vulnerable than others. Climate change will affect all natural and man-made systems to some extent. Commonwealth of Australia, (2005); Ebi et al., (2007); FAO, (2005); IPCC,(2001). However, the impacts on individual sectors or regions will vary depending on the sensitivity of the system and its adaptive capacity. Africa's vulnerability to climate change is exacerbated by a number of non-climatic factors, including endemic poverty, hunger, high prevalence of disease, chronic conflicts, low levels of development and low adaptive capacity FAO, (2009). The most vulnerable sectors include agriculture, biodiversity, water, health, forests and energy. Many of the factors that make climate change unique also make it complex. It is a multi-scalar environmental and social problem, which affects different sectors. Osbahr,(2007).

2.9.2 Climate Change Mitigation and Adaptation

Discussions about a society's response to climate change have revolved primarily around mitigation and adaptation. Climate change mitigation involves taking actions to reduce GHGs emissions and to enhance sinks aimed at reducing the extent of global warming. In the context of climate change, adaptation refers to adjustments in human and natural systems to respond to actual or expected climate impacts. IPCC, (2007); FAO, (2008*).* Adaptation involves initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects, where as mitigation deals with the causes of climate change, adaptation tackles the consequences. The extent and nature of climate change negative impacts can be managed by effective adaptation. IPCC, (2001); Stainforth et al., (2007).

Efforts to mitigate climate change and ensuring adaptation are crucial. Managing climate change impacts also depends on adjustments and changes at every level: community, national and international. The capacity to adapt to climate change will vary significantly from country to country, community to community and according to the level of development. Adaptation activities include behavioral, institutional and technological adjustments. These capture a wide array of potential strategies, such as forest protection, establishing corridors for migratory species, searching for drought resistant crops, altering planting patterns, forest management, as well as personal savings or insurance that may cover the damage expected by individuals (IPCC, (2001); Toman and Bierbaum, (1996).

2.10 SUSTAINABILITY

Claims of sustainability are virtually impossible to prove but enough is known about tropical forest ecology and silviculture to protect ecosystem functions and maintain biodiversity while still deriving financial profits from logging. Rapid improvements in long-term forest production will derive from better planning of harvesting operations and stand improvement treatments. Lack of good management plans generally results in logging practices that destroy natural regeneration and increase forest susceptibility to soil loss, wildfires, and weed infestations. Participation of forest managers, timber importers, researchers, and environmentalists in the development of methods for assessing the social and ecological impacts of tropical forestry operations inspires hope for sustainability

2.11 Sustainability of Forests

Ghana has 266 forest reserves, 216 of which occupy 1,634,100 hectares in the high forest zone Hawthorne and Abu-Juam (1995). The forest reserves were originally established to promote ecological stability, watershed protection and windbreaks, while seeking to guarantee the flow of goods and services for socio-economic development. In 1993, it was estimated that in areas outside permanently reserved forests, there was extreme deforestation pressure, leaving an estimated 400,000 hectares of forest cover ("off-reserves") from which comes most timber supply. FD (1993). Within forest reserves, there are some 15,000 hectares of timber plantations (mainly Tectona grandis, Cedrela odorata and Gmelina arborea) that provide the key source of transmission poles for rural electrification. FD,(1993). Recognizing the economic and environmental benefits from such plantations, private interests and communities have planted trees on an increasing scale around the country.

Based on the forest inventory, which started in 1986, forest reserves in the high forest zone are in classes according to the condition of the estate Ghartey, (1989), Wong, (1989).

2.12 Sustainable Forest Management

Sustainable forest management (SFM) implies various degrees of deliberate human intervention, ranging from actions aimed at safeguarding and maintaining the forest ecosystem and its functions, to favouring specific socially or economically valuable species or groups of species for the improved production of goods and services. FAO, (1999). SFM ensures that the values derived from the forest meet present-day needs while at the same time ensuring their continued availability and contribution to long-term development needs .FAO,(2008). It has a tremendous potential to serve as a tool in combating climate change, protecting people and livelihoods, and creating a foundation for more sustainable economic and social development. To minimize the impacts of climate change on forest ecosystems and forest-dependent people, countries will require flexible and equitable decision-making processes at local and national levels that allow for rapid and adaptable forest management practices. There is growing awareness that SFM should include measures for the effective conservation and management of forest resources in order to meet the actual and future needs of local people. Peters, (1996).

Prabhu (1996) defines sustainability forest management as a set of objectives, activities, and outcomes consistent with maintaining or improving the forest's ecological integrity and contributing to the peoples well being both now and in future. This definition encompasses all forest uses and services. In this study, sustainable forest management will be defined as a set of objectives and activities aimed at producing the optimum amount of timber and enforcing a harvesting regime such that an approximate balance can be achieved between growth an amount cut. This entails harvesting the wood at an average rate exceeding the forests' growth rate. The challenge here is not to stop the extraction activities but rather to manage them so that harvesting is done in a planned and controlled manner to ensure sustainability. The aim is to continue harvesting in years to come.

Allied to sustainability is the concept of maximum sustainability yield (MSY), which dates back to 18th century. In the contest of plantation forestry, MSY is the maximum biomass that one can remove from a plantation without decreasing the resource level.

Despite the criticisms by several authors like Clark (1976) and Hassan (1999), MSY leads to depletion of the resource during low natural growth periods we argue that it may conversely lead to underexploitaion during the low growth periods. So MSY is still a useful strategy for managing renewable resources such as forest. One can use mathematical model to predict MSY of a forest reserve.

2.13 History of Maximum Sustainability Yield

The concept of Maximum Sustainable Yield (MSY) as a fisheries management strategy was developed in the early 1930s. Russell (1931), Hjort et al (1933), Graham, (1935)

·It increased in popularity in the 1950s with the advent of surplus-production models with explicitly estimate MSY Schaefer, (1954). As an apparently simple and logical management goal, combined with the lack of other simple management goals of the time, MSY was adopted as the primary management goal by several international organizations (e.g., IWC, IATTC ,ICCAT, ICNAF), and individual countries. Mace, (2001)

Between 1949 and 1955, the U.S. maneuvered to have MSY declared the goal of international fisheries management. Johnson(2007). The international MSY treaty that was eventually adopted in 1955 gave foreign fleets the right to fish off any coast. Nations that wanted to exclude foreign boats had to first prove that its fish were overfished. Botsford et al (1997)

As experience was gained with the model, it became apparent to some researchers that it lacked the capability to deal with the real world operational complexities and the influence of trophic and other interactions. In 1977, Larkin wrote its epitaph, challenging the goal of maximum sustained yield on several grounds: It put populations at too much risk; it did not account for spatial variability in productivity; it did not account for species other than the focus of the fishery; it considered only the benefits, not the costs, of fishing; and it was sensitive to political pressure .Larkin (1977).

In fact, none of these criticisms was aimed at sustainability as a goal. The first one noted that seeking the absolute MSY with uncertain parameters was risky. The rest point out that the goal of MSY was not holistic; it left out too many relevant features.(Botsford et al 1997)

Some managers began to use more conservative quota recommendations, but the influence of the MSY model for fisheries management still prevailed. Even while the scientific community was beginning to question the appropriateness and effectiveness of MSY as a management goal, Sissenwine, (1978) it was incorporated into the 1982 United Nations Convention for the Law of the Sea, thus ensuring its integration into national and international fisheries acts and laws.Larkin (1977).

According to Walters and Maguire, an ‘‘institutional juggernaut had been set in motion’’, climaxing in the early 1990s with the collapse of northern cod. Walters and Maguire, (1996)

Bell and Morse (1999) summarized MSY in the following manner: ‘Any species each year produces a harvestable surplus and if you take that much no more, you can go on getting it forever and ever’. However this is a difficult thing to do, as it requires that one knows precisely the “harvestable surplus” each year. Rather, for practical purposes MSY will be interpreted to mean a harvesting rate equal to the constant growth rate of the timber growing stock, approaches its carrying capacity, which in case of trees is the maximum number of trees or biomass an environment can support.

2.13.1 Maximum sustainable yield

In population ecology and economics, Maximum Sustainable Yield or MSY is, theoretically, the largest yield (or catch) that can be taken from a species' stock over an indefinite period. Fundamental to the notion of sustainable harvest, the concept of MSY aims to maintain the population size at the point of maximum growth rate by harvesting the individuals that would normally be added to the population, allowing the population to continue to be productive indefinitely. Under the assumption of logistic growth, resource limitation does not constrain individuals' reproductive rates when populations are small, but because there are few individuals, the overall yield is small. At intermediate population densities, also represented by half the carrying capacity, individuals are able to breed to their maximum rate. At this point, called the maximum sustainable yield, there is a surplus of individuals that can be harvested because growth of the population is at its maximum point due to the large number reproducing individuals. Above this point, density dependent factors increasingly limit breeding until the population reaches carrying capacity. At this point, there are no surplus individuals to be harvested and yield drops to zero. The maximum sustainable yield is usually higher than the optimum sustainable yield and maximum economic yield.

MSY is extensively used for fisheries management. Unlike the logistic Schaefer (1954) model, MSY has been refined in most modern fisheries models and occurs at around 30% of the unexploited population size. This fraction differs among populations depending on the life history of the species and the age-specific selectivity of the fishing method.

However, the approach has been widely criticized as ignoring several key factors involved in fisheries management and has led to the devastating collapse of many fisheries. As a simple calculation, it ignores the size and age of the animal being taken, its reproductive status, and it focuses solely on the species in question, ignoring the damage to the ecosystem caused by the designated level of exploitation and the issue of by catch. Among conservation biologists it is widely regarded as dangerous and misused.

2.13.2 Uses of Maximum Sustainable Yield

Maximum Sustainable Yield (MSY) has been especially influential in the management of renewable biological resources such as commercially important fish and wildlife. In fisheries terms, maximum sustainable yield (MSY) is the largest average catch that can be captured from a stock under existing environmental conditions. MSY aims at a balance between too much and too little harvest to keep the population at some intermediate abundance with a maximum replacement rate.

Relating to MSY, the Maximum Economic Yield (MEY) is the level of catch that provides the maximum net economic benefits or profits to society. Like optimum sustainable yield, MEY is usually less than MSY.

CHAPTER 3

3.0 Introduction

Growth models assist forest researchers and managers in many ways. Some important uses include the ability to predict future yields and to explore silvicultural options. Models provide an efficient way to prepare resource forecasts, but a more important role may be their ability to explore management options and silvicultural alternatives. For example, foresters may wish to know the long-term effect on both the forest and on future harvests of a particular silvicultural decision, such as changing the cutting limits for harvesting. With a growth model, they can examine the likely outcomes, both with the intended and alternative cutting limits, and can make their decision objectively. The process of developing a growth model may also offer interesting new insights into stand dynamics. Richard Haberman (1977).

According to Richard (1977), growth models offer forest managers a powerful analytical tool to investigate quickly and efficiently, the response of the forest to various management regimes. They allow foresters to determine a regime that should maximize volume or value production, or maximize the production of a particular product. It also enables them to determine the effect of a revised harvest programme to exploit a change in demand. They can investigate effects of many constraints on forest operations, and their effect on yields. But the most powerful feature is the ability of the model to assist managers to make reliable long-term forecasts, so that they can make long term commitments to the capital intensive.

This study attempts to add up to growth models thus making it more accessible to foresters and others interested in forests, whether planted or natural. There is an increasing interest in, and controversy surrounding the use of mixed plantations and natural forests, and rational discussion during recent years, vast areas of natural forest, especially in the tropics, have been logged or converted to other uses. Well-meaning forest managers have often been over-optimistic in estimating forest growth and yields, and this has contributed to over-cutting in some forests. Growth models can provide objective forecasts, offering forest managers the information needed to maintain harvests within the sustainable capacity of the forest, and providing quantitative data for land use planners to make informed decisions on land use alternatives. In this way, I hope that this study will contribute to the conservation and sustainable management of natural forests in the tropics and elsewhere.

3.1 POPULATION GROWTH MODELS

In formulating a model of the population growth of a species, we must decide what factors affect that population. Clearly in some cases it depends on many quantities. For example the population of sharks in the Adriatic Sea will depend on the number of fish available for sharks to feed on (if there are none, sharks would become extinct). In addition the presence of harmful bacteria will affect a number of sharks. It would be incorrect to assume that the population of sharks is affected only by other species. Christy and Scott (1965).

In this study, the main concern is to formulate a harvesting model using logistic equation. The logistic model (or logistic function) is a function that is used to describe bounded population growth under the previous two assumptions: populations of organisms grow and replace themselves and growth rates, survival rates, and reproductive rates increase when harvesting reduces population density, Russell, (1931) .The logistic function is bounded at both extremes: when there are not individuals to reproduce, and when there is an equilibrium number of individuals (i.e at carrying capacity). Under the logistic model, population growth rate between these two limits is most often assumed to be sigmoidal. There is scientific evidence that some populations do grow in a logistic fashion towards a stable equilibrium – a commonly cited example is the logistic growth of yeast.

According to Milner-Gulland and Mace (1998) the equation describing logistic growth is

$$N_t = \frac{K}{1+\frac{K-No}{No}e^{-rt}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.1.1)$$

Where

N_t =The population size at time t

K=The carrying capacity of the population

N_0=The population size at time zero

r= rate of population increase

From the logistic function, the population size at any point can be calculated as long as r, K, and N_0 are known.

Differentiating equation (3.1.1) with respect to time the rate of change in population.

At first, the population growth rate is fast, but it begins to slow as times goes on, until it levels off to zero and then begins to decrease.

The equation (3.12) is the differential of the equation 3.1.1 Milner- Gulland and Mace (1998) $\frac{dN}{dt} = rN\left(1-\frac{N}{K}\right)\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.1.2)$

$\frac{dN}{dt}$ can be understood as the change in population (N) with respect to a change in time (t). Equation (3.1.2) is the usual way in which logistic growth is represented mathematically and has several important features. First, at very low population sizes, the value of $\frac{N}{K}$ is small, so the population growth rate is approximately equal to rN meaning the population is growing exponentially at a rate r (the intrinsic rate of population increase). Despite this, the population growth rate is very low (low values on the y-axis of figure 3.1.2) because, even though each individual is reproducing at a high rate, there are few reproducing individuals present. Conversely, when the population is large the value of $\frac{N}{K}$ approaches 1 effectively reducing the terms inside the brackets of equation (3.1.2) to zero. The effect is that the population growth rate is again very low, because either each individual is hardly reproducing or mortality rates are high. Milner-Gulland and Mace (1998). As a result of these two extremes, the population growth rate is maximum at an intermediate population or half the carrying capacity $(N = \frac{k}{2})$.

3.2 A DISCRETE ONE - SPECIES MODEL

One of the simplest models of population growth of a species is developed. In a population growth species, measurements were taken over an interval at time Δt. The rate of change of the population as measured over the time interval Δt would be

$$\frac{\Delta N}{\Delta t} = \frac{N(t+\Delta t) - N(t)}{\Delta t} \quad \text{...} \quad (3.2.1)$$

This indicates the absolute rate of increase of the population. A quantity which will prove to be quite important is the rate of change of the population per individual $R(t)$. This is called the growth rate per unit time (for example per year) as measured over the time interval Δt:

$$R(t) = \frac{N(t+\Delta t) - N(t)}{\Delta t N(t)} \quad \ldots\ldots \quad (3.2.2)$$

The percentage change in the population is $\frac{100\Delta N}{N(t)} = 100R(t)\Delta t$

Thus one hundred times the growth rate $R(t)$ is the percentage change in the population per unit time. For example if one-half year population increases by 20% then $R(t) = \frac{2}{5}$ and the growth rate is 40% per year as measured for one-half year equation (3.2.2) cannot be used to determine population at future times since it is just the definition of $R(t)$. However, if the growth rate and the initial population were known then the population at later times could be calculated.

$$N(t+\Delta t) = N(t) + \Delta t R(t) N(t) \quad \ldots\ldots \quad (3.2.3)$$

We assume that the population of the species only changes due to births and deaths. No outside experimenter ship some extra species into the system. There is no migration into or out of the region.

Thus $N(t+\Delta t) = N(t) +$ (number of births) – (number of deaths)

The reproductive (birth) rate b per unit time measured over the time interval Δt and the death rate d are defined as

$$b = \frac{Number\ of\ births}{\Delta t N(t)} \quad \ldots\ldots \quad (3.2.4)$$

$$d = \frac{Number\ of\ deaths}{\Delta t N(t)} \quad (3.2.5)$$

Consequently.

The population at a time Δt later is

$$N(t+\Delta t) = N(t) + \Delta t\ (b-d)N(t) \quad (3.2.6)$$

The growth rate R, $R = b - d$ ………………..………………………… (3.2.7)

Equation (3.2.7) is the birth rate minus the death rate

As first step in mathematical modeling of population growth, we assume that the number of deaths and the number of deaths are simply proportional to the total population. Thus the growth rate $R = R_o$: it is assumed not to change in time.

A two fold increase in the population yields twice as many births and deaths. If the growth rate is constant then for any t is given by

$$N(t+\Delta t) - N(t) = R_0 \Delta t N(t) \quad (3.2.8)$$

This can be expressed as a differential equation for the population

$$N(t+\Delta t) = (1 + R_o \Delta t) N(t) \quad (3.2.9)$$

The population at a time Δt later is a fixed percentage of the previous population this differential $\boxed{N(t_o) = N_o}$

Equation can be solved as an initial value problem that is given an initial population at $t = t_o$

the future population can be easily computed.

3.3 EXPONENTIAL GROWTH MODEL

The definition of the growth rate is

$$R(t) = \frac{N(t+\Delta t) - N(t)}{\Delta t N(t)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (3.3.1)$$

In general, this growth rate depends on time. It is calculated over a time intervals of length Δt .By this definition, the growth rate also depends on the measuring time interval. More likely of interest is the instantaneous growth rate (which we will now refer to as the growth rate)

$$R(t) = \lim \frac{N(t+\Delta t) - N(t)}{\Delta t N(t)} = \frac{1}{N}\frac{dN}{dt} \quad \text{as } \Delta t \to 0 \quad \ldots\ldots\ldots\ldots\ldots.. \ (3.3.2)$$

For this to be meaningful, the population must be approximated as a continuous function of time which is assumed to be differentiable. This approximation is most reasonable for large populations. The growth rate is the rate of change in the population per individual. Alternatively, the rate of change of the population $\frac{dN}{dt}$, equals the growth rate R , times the population N .

As a first model we again assume the growth rate is a constant. If this growth is constant R_o, then the population growth is described by the solution to the first order linear differential equation with constant coefficients

$$\frac{dN}{dt} = R_0 N \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (3.3.3),$$

which satisfies the initial condition $N(t_0) = N_0$

The solution exhibits exponential behavior

For $R_0 > 0$. $N(t) = N_0 \mathrm{e}^{R_0(t-t_0)}$ ……………… (3.3.4)

A population grows exponentially if the growth rate is a positive constant.

If $R_0 > 0$

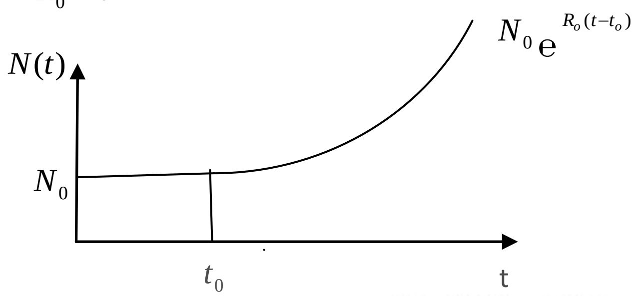

Figure 3.3.1 Exponential growth

Similarly a population decays exponentially if its growth rate is negative constants as shown below. (it is often convenient to let the initial $t_0 = 0$)

If $R < 0$

Figure 3.3.2 Exponential Decay

Of interest is the time necessary for a population to double if the growth rate is a positive constant. The length of time $t_i - t_0$ such that the population doubles $N(t_1) = 2N(t_0)$ is obtained from the expression $2N_o e^{R_o(t_1 - t_o)}$, N_o cancels hence the time it takes to double does not depend on the initial population. In particular

$$t_1 - t_0 = \frac{\ln 2}{R_0} \quad \text{...} \quad (3.3.5)$$

But $\ln 2 \approx 0.69315$. This can be applied to the following problem. If a population grows continually at the instantaneous rate of 2% a year $(R_0 = 0.02\%)$, then in how long will the population double? The required time

$$t_1 - t_0 \approx \frac{0.69315}{0.02} = 35 \text{ years}$$

Thus the population doubles in approximately.

If R_0 is the instantaneous growth rate per year , then in one year , the population will have grown from N_0 to $N_0 e^{R_0}$ .The measured growth rate over that one year is

$$\frac{1}{N_o}\frac{\Delta N}{\Delta t} = \frac{N_o e^{R_o}}{N_o} = e^{Ro} - 1 \text{ ………………………………………….(3.3.6)}$$

3.4 LOGISTIC GROWTH MODEL

3.4.1 EXPLICIT SOLUTION OF LOGIST.IC EQUATION

Although the logistic equation, $\frac{dN}{dt} = N(a - bN)$

An explicit solution to the logistic equation can be obtained since the equation is separable:

$$\int \frac{dN}{N(a-bN)} = \int dt$$

Using integration by partial fraction

$$\int \frac{dN}{N(a-bN)} = \int \frac{1/a}{N} dN + \int \frac{b/a}{a-bN} dN$$

$$\int \frac{dN}{N(a-bN)} = \int \frac{1}{aN} dN + \int \frac{b}{a(a-bN)} dN = \int dt$$

$$\frac{1}{a}\ln|N| + \frac{b}{a}\ln|a-bN| \left(-\frac{1}{b}\right) = t + c$$

$$\frac{1}{a}\ln|N| - \frac{1}{a}\ln|a-bN| = t + c$$

$$\frac{1}{a}\left[\ln|N| - \ln|a-bN|\right] = t + c$$

where the absolute values in the resulting logarithms can be very important. The arbitrary constant C enables the initial value problem $N(0) = N_0$ to be solved. Eliminating C in that way yields

$$\frac{1}{a}\left[\ln|N| - \ln|a-bN|\right] = t + \frac{1}{a}\left[\ln|N_0| - \ln|a-bN_0|\right]$$

Since both N and N_0 must be positive

$$\frac{1}{a}\ln\frac{N}{N_0} + \frac{1}{a}\ln\left|\frac{a-bN_0}{a-bN}\right| = t$$

This equation gives t as a function of N, not a desirable form. Multiply by a and exponentiating yield

$$\frac{N}{N_o}\left|\frac{a-bN_o}{a-bN}\right| = e^{at}$$

$a-bN_0$ and $a-bN$ have the same sign and hence

$$\frac{N}{N_0}\left(\frac{a-bN_0}{a-bN}\right) = e^{at}$$ or equivalently $N(a-bN) = (a-bN)N_o e^{at}$

Solving for N yields

$$N = \frac{aN_o e^{at}}{a-bN_o+b}$$

3.5 MODEL FORMULATION

The Assumption of the model

The key assumption behind all sustainable harvesting models such as MSY is that populations of organisms grow and replace themselves – that is, they are renewable resources. Additionally it is assumed that because the growth rates, survival rates, and reproductive rates increase when harvesting reduces population density, Russell, (1931) they produce a surplus of biomass that can be harvested. Otherwise, sustainable harvest would not be possible; some of this does not make sense

Another assumption of renewable resource harvesting is that populations of organisms do not continue to grow indefinitely; they reach an equilibrium population size, which occurs when the number of individuals matches the resources available to the population (i.e., assume classic logistic growth). At this equilibrium population size, called the carrying capacity, the population remains at a stable size. Milner-Gulland and Mace (1998).

3.5.1 LOGISTIC GROWTH MODEL

.The logistic model (or logistic function) is a function that is used to describe bounded population growth under the previous two assumptions. The logistic function is bounded at both extremes: when there are not individuals to reproduce, and when there is an equilibrium number of individuals (i.e., at carrying capacity). Under the logistic model, population growth rate between these two limits is most often assumed to be sigmoidal. There is scientific evidence that some populations do grow in a logistic fashion towards a stable equilibrium – a commonly cited example is the logistic growth of yeast.

In the 1940s Verhust used this observation to develop a mathematical model called the logistic model.

Edwards and Hanson (1989) express this model by differential equation

$$\frac{dB}{dt} = rB\left[1 - \frac{B}{K}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.6.1.1)$$

Where

$\frac{dB}{dt}$ = rate of change of biomass ($m^3 yr^{-1}$),

B = Total biomass (m^3),

K = The carrying capacity (m^3)

r = proportional growth rate of biomass (yr^{-1})

Bio – mathematicians and bio – economist such as Clark (1976) and Murry (1993) have used this model to predict growth and sustainable yield of renewable resources such as forest. In forestry, the logistic model has been used to predict the growth of a forest so that forester can match harvesting and selling plans against the prediction of growth and thereby conclude whether they are cutting more or less than, or an amount equal to the growth.

However, there is scant literature on the use of logistic model in predicting the sustainable levels of harvesting forest reserves. Therefore, this study attempts to use logistic model to predict maximum sustainable yield (MSY) of a forest reserve.

When a resource such as trees is being harvested, the rate of change of biomass given in equation (1) is reduced to reflect the harvest. Defining the effort involved in harvesting, E

(yr^{-1}), to be the proportion of harvested to the total biomass per year transforms equation (3.6.1.1) to:

$$\frac{dB}{dt} = rB\left[1 - \frac{B}{K}\right] - EB \qquad (3.6.1.2)$$

Which can be re - written as

$$\frac{1}{B}\frac{dB}{dt} = (r - E) - \frac{r}{k}B \qquad (3.6.1.3)$$

If the rates of change of biomass and total biomass are known for a period of several years, one can use equations (3.6.1.2) and (3.6.1.3) to estimate effort, the proportional growth rate of biomass and the carrying capacity and hence, estimate MSY of a forest reserve.

Most sustainable harvesting models include economic discounting, which generally reduce the rotation period of the tree stands and sustainability levels. Since our study was restricted to productivity of the plantations versus sustainable harvesting levels, economic factors were not considered. Clark (1976) and Murry (1993).

3.6 DERIVATION OF MAXIMUM SUSTAINABLE YIELD USING THE LOGISTIC MODEL

The concept of maximum sustainability yield is based on the fundamental ecological concept of population growth that incorporates the notion of carrying capacity. It is generally observed that growth rate of any living organism follows sigmoid curve which increases slowly during the early ages, rapidly during middle ages, then slows again during maturity as the population approaches its carrying capacity, which in case of trees is the maximum number of trees or biomass an environment can support.

Maintaining a constant resource level is equivalent to maximizing the stand biomass, so as to maintain a constant stocking. In terms of our model, this means the rate of change of biomass, $\frac{dB}{dt}$, should equal to zero. Solving for B in equation (3.6.1.2) under these conditions yields

$$B = K\left[1-\frac{E}{r}\right] \qquad (3.7.1)$$

As the steady state of stand biomass, and

$$B_{MSY} = EK\left[1-\frac{E}{r}\right] \qquad (3.7.2)$$

As the maximum sustainable yield (MSY)

It can be seen that if the effort is greater than the proportional growth rate, then in long run the only realistic steady will be $B = 0$, which implies depletion of the biomass resource. Therefore to achieve sustainability and ensure a steady state of the resource, the effort must be less than the proportional growth rate of biomass. Knowing the values of E sustainable, r and K permits a determination of sustainable levels of harvest.

3.7 ESTIMATION OF EFFORTS, CARRYING CAPACITY AND PROPORTIONAL GROWTH RATE OF BIOMASS

To estimate the rate of harvesting, it is enough to determine the effort E. Since the amount of Biomass harvested, B_h is given by the linear model of the form

$$B_h = EB \qquad (3.8.1)$$

then E can be estimated by using Microsoft Excel .

To estimate the proportional growth rate biomass and the carrying capacity, we need to estimate the parameters $(r-E)$ and $-\frac{r}{k}$ from equation (3.6.2.3) first. This equation suggests that linear model of the form

$$Y = \theta - \alpha B \qquad (3.8.2)$$

Where $Y = \frac{1}{B}\frac{dB}{dt}$, $\theta = r - E$ and $\alpha = \frac{r}{k}$, is expected. Hence one can use least squares method to estimate the parameters θ and α. Applying the least squares criterion Giodano, F. R. (1997)

$$\alpha = \frac{1}{\Delta}\left\{\sum_{i=1}^{N} B_i y_i - \sum_{i=1}^{N} B_i \sum_{i=1}^{N} y_i\right\} \qquad (3.8.3)$$

$$\theta = \frac{1}{\Delta}\left\{\sum_{i=1}^{N} B_i^2 \sum_{i=1}^{N} y_i - \sum_{i=1} B_i \sum_{i=1} B_i y_i\right\} \qquad (3.8.4)$$

Where N is the number of years for which data is collected, (y_i, B_i) the data points being used for $1 \le i \le N$ and $\Delta = N\sum_i B_i^2 - \left(\sum_i Bi\right)^2$

In this study equations (3.8.2) and (3.8.3) were used to estimate the parameters $\theta = r - E$ and $\alpha = \frac{r}{K}$, and hence, to estimate the proportional growth rate of biomass, r and carrying capacity, K, in order to compute the study states and maximum sustainable harvesting levels of biomass.

3.8 IMPLICATION OF MSY MODEL

Starting to harvest a previously unharvested population will always lead to a decrease in the population size. That is, it is impossible for a harvested population to remain at its original carrying capacity. Instead, the population will either stabilize at a new lower equilibrium size or, if the harvesting rate is too high, decline to zero.

The reason why populations can be sustainably harvested is that they exhibit a density-dependent response. Jennings et al (2001). This means that at any population size below K, the population is producing a surplus yield that is available for harvesting without reducing population size. Density dependence is the regulator process that allows the population to return to equilibrium after a perturbation. The logistic equation assumes that density dependence takes the form of negative feedback. Milner-Gulland and Mace (1998).

If a constant number of individuals is harvested from a population at a level greater than the MSY, the population will decline to extinction. Harvesting below the MSY level leads to a stable equilibrium population if the starting population is above the unstable equilibrium population size.

3.9 LIMTATIONS OF MSY APPROACH

Although it is widely practiced by state and federal government agencies regulating wildlife, forests, and fishing, MSY has come under heavy criticism by ecologists and others from both theoretical and practical reasons.Milner-Gulland and Mace (1998). The concept of maximum sustainable yield is not always easy to apply in practice. Estimation problems arise due to poor assumptions in some models and lack of reliability of the data.Townsend et al (2008).

Biologists, for example, do not always have enough data to make a clear determination of the population's size and growth rate. Calculating the point at which a population begins to slow from competition is also very difficult. The concept of MSY also tends to treat all individuals in the population as identical, thereby ignoring all aspects of population structure such as size or age classes and their differential rates of growth, survival, and reproduction. Townsend et al (2008)

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.0 DATA COLLECTION

This chapter deals with the analysis of the data that has been collected. A secondary data was collected from Begoro Forest Plantation and amount of biomass harvested in each year was from 2005 to 2012 .The species used in the forest plantation were Teak and Cebrela.The data on the planted area (compartments), tree growth, damage and harvesting were collected and analysed using Linest function in Microsoft Excel software. The results are presented in three sections; actual biomass versus harvestable surplus, change in total biomass with the final section estimating effort, proportional growth rate, carrying capacity, steady states and sustainable harvesting levels. The main purpose is to use a mathematical model to predict sustainable levels of harvesting the tree crops in the forest plantation. The tables below showed the data collected.

Table 4.1: **Data for the species Teak**

Year	Total Biomass B (m^3)	Biomass Harvested B_h (m^3)	Biomass Damaged B_d (m^3)	Biomass Closed B_c=B-B_h-B_d (m^3)	Biomass Opened $B^i_{op}=B_c^{i+1}$ (m^3)	Change in Biomass $\Delta B=B_c - B_{op}$ (m^3y^{-1})	$Y=\frac{1}{B}\frac{dB}{dt}$
2005	90,179	81,592	5,559	3,028	-	3,028	0.03358
2006	100,086	61,825	2,781	35,480	3,028	32,452	0.32424
2007	107,211	55,049	2,140	50,022	35,480	14,542	0.13564
2008	107,899	47,290	3,556	57,053	50,022	7,031	0.06516
2009	110,542	47,617	284	62,641	57,053	5,588	0.05055
2010	114,730	7,832	784	106,114	62,641	43,473	0.37892
2011	163,419	8,713	530	154,176	106,114	48,062	0.29410
2012	215,121	76,652	4,357	134,112	154,176	-20,064	-0.09327

Table 4.2: Data for the species Cebrela

Year	Total Biomass B (m^3)	Biomass Harvested B_h (m^3)	Biomass Damaged B_d (m^3)	Biomass Closed $B_c=B-B_h-B_d$ (m^3)	Biomass Opened $B^i_{op}=B_c^{i+1}$ (m^3)	Change in Biomass $\Delta B=B_c-B_{op}$ (m^3y^{-1})	$Y=\frac{1}{B}\frac{dB}{dt}$
2005	27,616	9,134	310	18,172	-	18,172	0.65802
2006	30,899	12,731	218	17,950	18,172	-222	-0.00718
2007	31,798	10,821	438	20,539	17,950	2,589	0.08142
2008	34,982	13,183	1,245	20,554	20,539	15	0.00043
2009	40,135	11,293	1, 081	18,761	20,554	-1,793	-0.04467
2010	45,742	14,472	945	30,325	18,761	11,564	0.25281
2011	61,131	21,824	2,732	36,575	30,325	6,250	0.10223
2012	64,894	15,913	1,898	47,083	36,575	10,508	0.16193

Table 4.3: Comparism of Actual Biomass Harvested and Biomass Increment

Year	Actual Biomass Harvested (m^3)	Biomass Increment (Harvestable Surplus) (m^3)
2005	127,000	22,583
2006	139,000	31,692
2007	141,000	35,812
2008	158,000	22,392
2009	138,000	21,819
2010	161,000	22,896
2011	157,000	21,083
2012	140,000	20,119

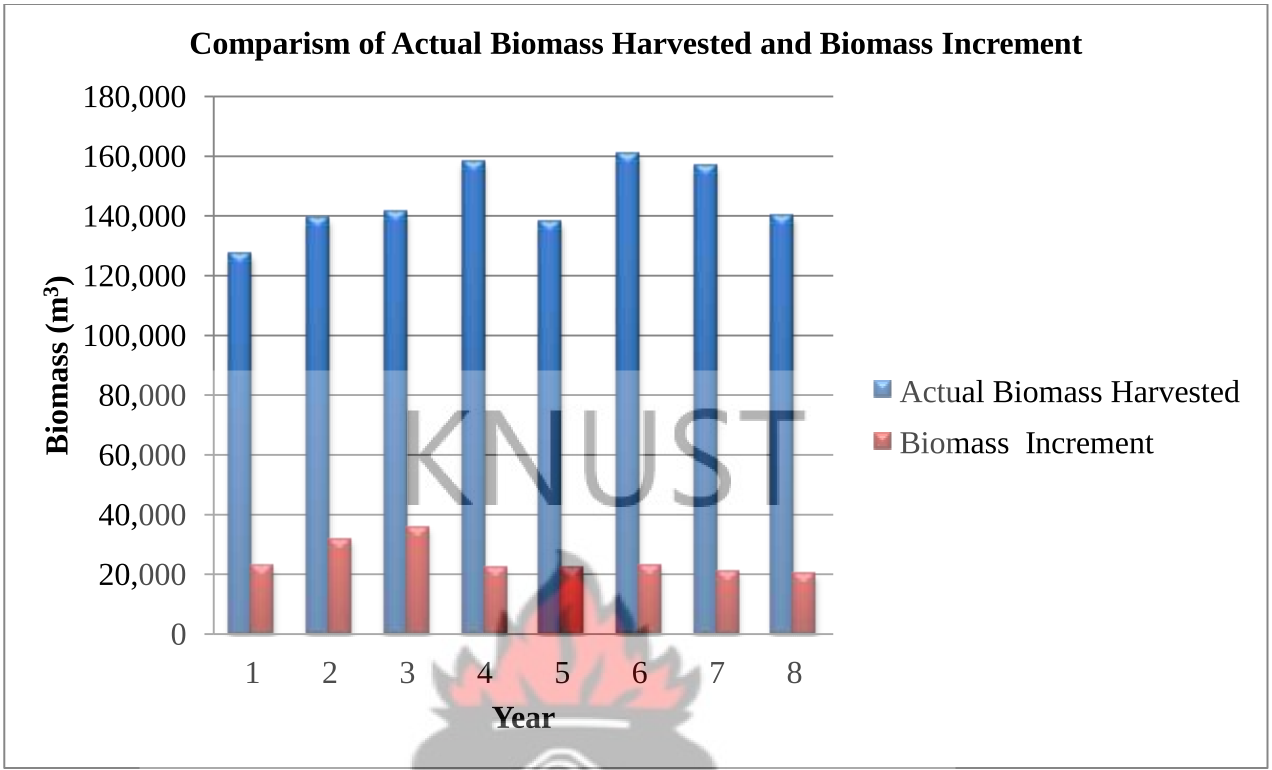

Figure 4.1: Comparism of Actual biomass harvested and biomass increment

4.1 Comparism of Actual biomass harvested and biomass increment (harvestable surplus)

Comparison of actual biomass harvested and biomass increment (harvestable surplus) reveals that more wood is being harvested than the forest growth rate (see Table 4.1 and Figure 4.1). It is apparently from Figure 1 that the general tendency has been to harvest more biomass than the annual increment. Thus shows that the current harvesting rate which is about 129,000 m^3per year on average (an effort of 0.345), is not sustainable and may lead to decrease the total biomass in the forest plantation. From the foregoing discussion on sustainable forest management, it is clear that, to ensure sustainability, biomass less than or equal to the increment (harvestable surplus) should have been harvested in each year.

Table 4.4: Trends in Total Biomass (cubic meters)

Year	Teak	Cebrela
2005	90,179	27,616
2006	100,086	30,899
2007	107,211	31,798
2008	107,899	34,982
2009	110,542	40,135
2010	114,730	45,742
2011	163,419	61,131
2012	215,121	64,894

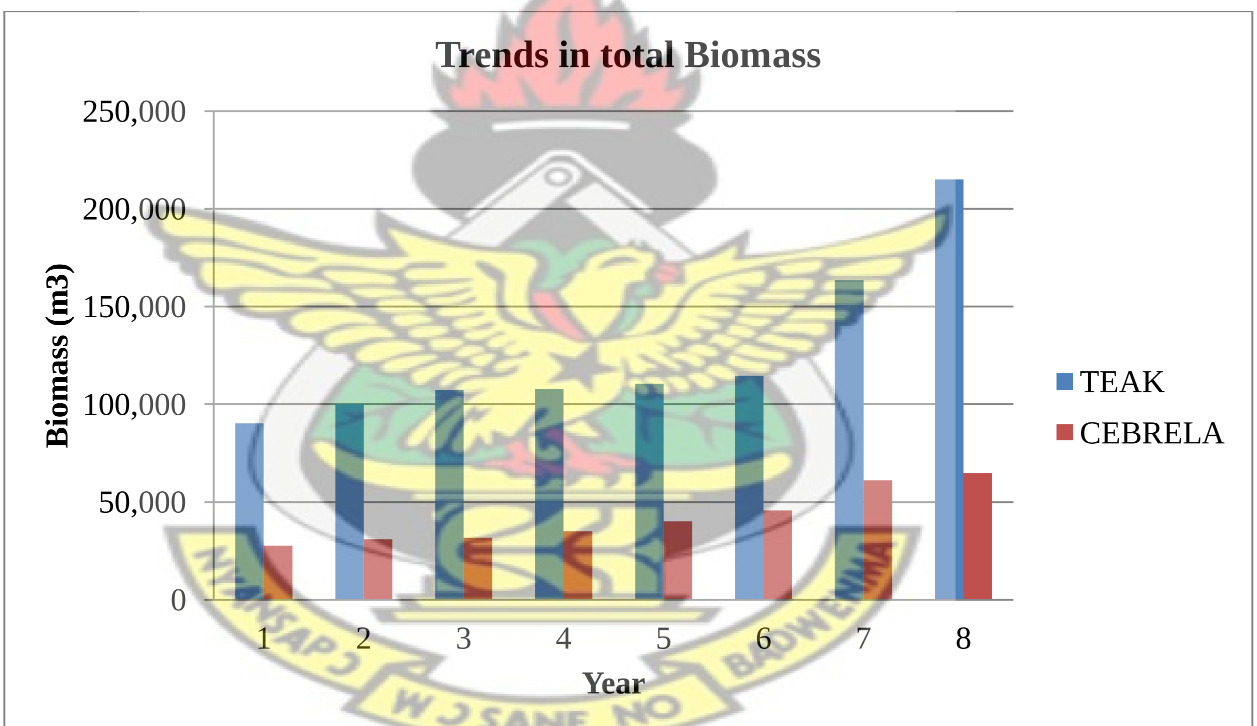

Figure 4.2: Trends in Total Biomass

4.2 Trends in Total Biomass

As expected from the unsustainable harvesting, it was found that the total biomass for the two species was generally increasing with respect to time (see Table 4.4 and Figure 4.2).

Since Teak is the most dominant species in the forest plantation (with biomass of more than 72% of the total biomass), its change in biomass is more prominent than that for the other species. Therefore, changes in total biomass based on this species will now be fully discussed.

The results for Teak indicate show that there has been increase since 2003. However, there is a slight decrease since 2007. This may suggest that the biomass is cyclic and that it is beginning to increase again. However, to be certain of this cyclic behavior, one would to have data sets for relatively longer period of time than that covered by this study.

4.3 Results and Discussion

4.3.1 Estimation of the Effort E, Growth rate r, and Carrying capacity k

Species: Teak

By using the linear model $Y = \theta - \alpha B$

where θ = the intercept, $-\alpha$ = the slope

B_h= Biomass harvested

B= Total biomass

$$E = \frac{\sum_{i=1}^{n=8} B_h}{\sum_{i=1}^{n=8} B}$$

$$E = \frac{389570}{1009187} = 0.38717$$

$r - E = \theta$ but $\theta = 0.30601$

$$r - 0.38717 = 0.30601$$

$$r = 0.38717 + 0.30601$$

$$r = 0.69318$$

$$\alpha = -\frac{r}{k} \quad \text{but} \quad \alpha = -1.2856 \times 10^{-6}$$

$$-1.2856 \times 10^{-6} = -\frac{0.69318}{k}$$

$$k = \frac{0.69318}{-1.2856 \times 10^{-6}} = 553{,}923.6056$$

$$k \approx 553{,}900$$

Species: Cebrela

By using the linear model $Y = \theta - \alpha B$

where θ = the intercept, $-\alpha$ = the slope

B_h= Biomass harvested

B= Total biomass

$$E = \frac{\sum_{i=1}^{n=8} B_h}{\sum_{i=1}^{n=8} B}$$

$$E = \frac{109371}{337197} = 0.32435$$

$$r - E = \theta \quad \text{but} \quad \theta = 0.26295$$

$$r - 0.32435 = 0.26295$$

$$r = 0.32435 + 0.26295$$

$$r = 0.5873$$

$$\alpha = -\frac{r}{k} \quad \text{but} \quad \alpha = -2.66491 \times 10^{-6}$$

$$-2.66491 \times 10^{-6} = -\frac{0.5873}{k}$$

$$k = \frac{0.5873}{2.66491 \times 10^{-6}} = 220{,}382.6771$$

$$k \approx 220{,}400$$

Table 4.5: Estimates of Effort, Proportion Growth Rate and Carrying Capacity

Species	Effort (E)	Proportional Growth Rate (r)	Carrying Capacity (k)
Teak	0.38717	0.69318	553,900
Cebrela	0.32435	0.5873	220,400

Table 4.5 above shows the estimated values of the effort (E) proportional growth rate of biomass (r) and carrying capacity (K) from the two species as calculated from table 4.1 and 4.2.

Since effort is defined as the proportion of harvested to the total biomass. The values listed in the Table 4.5 imply that to achieve sustainability, at most 38.717% of Teak and 32.435% of Cebrela biomass should be harvested each year. This is appropriate for sustainability purposes because in each case, the proportional harvests (E) are less than the proportional growth rates (r). Any harvest beyond these efforts is unsustainable.

The carrying capacities mean that if all harvesting activities were suspended and proper management practices were followed, then at their rotation ages, the species would over time; grow to a maximum biomass of about $553{,}900$ cubic meters and $220{,}400$ cubic meters respectively.

4.3.2 Estimation of the Steady States (SS), and Maximum Sustainable Yields (MSY)

Species : Teak

$$B_{ss} = K\left[1 - \frac{E}{r}\right]$$

$$B_{ss} = 553{,}900\left[1 - \frac{0.38717}{0.69318}\right] = 553{,}900[1 - 0.55854]$$

$$B_{ss} = 553{,}900[0.44146]$$

$$B_{ss} = 244{,}524.694$$

$$B_{ss} \approx 244{,}500$$

$$B_{msy} = EK\left[1 - \frac{E}{r}\right]$$

$$B_{msy} = 553{,}900(0.38717)\left[1 - \frac{0.38717}{0.69318}\right]$$

$$B_{msy} = (214{,}453.463)[0.44146] = 94{,}672.62578$$

$$B_{msy} \approx 94{,}700$$

Species: Cebrela

$$B_{ss} = K\left[1 - \frac{E}{r}\right]$$

$$B_{ss} = 220{,}400\left[1 - \frac{0.32435}{0.5873}\right] = 220{,}400[1 - 0.55227]$$

$$B_{ss} = 220{,}400[0.44773] = 98{,}679.692$$

$$B_{ss} \approx 98{,}700$$

$$B_{msy} = EK\left[1 - \frac{E}{r}\right]$$

$$B_{msy} = 0.32435(220{,}400)\left[1 - \frac{0.32435}{0.5873}\right] = 71{,}486.74[0.44773]$$

$$B_{msy} = 32{,}006.7581$$

$$B_{msy} = 32{,}000$$

Table4.6: Maximum Sustainable Yields (MSY) and Steady States (SS) for Teak and Cebrela

Species	MSY (m^3)	SS (m^3)
Teak	94,700	244,500
Cebrela	32,000	98,700

The maximum sustainable yields mean that, to ensure sustainability, at most 94,700 cubic meters of Teak and 32,000 cubic meters. Thus the total sustainable harvest for the forest plantation appears to be 126,700 cubic meters per year.

4.4. Discussion

The steady states mean that if the sustainable harvesting level are used followed by immediate replanting of the felled areas, then in the long run there will be a constant resource level of about 34,300 cubic meters given by the sum of these steady states.

Taking the total biomass to be the sum of individual steady states, this harvest is equivalent to felling about 30 hectares of 30 year old Teak every year and it represents an effort of about 0.0399. It must be pointed out that these sustainable harvests include wood left in the field in the form of branches and end portions constitutes about 24% of the total harvest. Therefore the realistic sustainable harvest is 76% of the levels suggested in this study.

It must be borne in mind that the sustainable harvesting levels were arrived at by using the logistic equation. In practice, however, silvicultural operations such as pruning are untimely or not followed at all. This nullifies any potential to be realized from such operations. In reality, periodic mean increments are affected by site factors like soil fertility and moisture. Moreover, the accuracy of actual biomass harvested depends on the forest assistants' efficiency in the estimating standing biomass and recording the exact biomass harvested per compartment and species. Also, in trend studies data taken over a long period of time are needed in order to make better predictions. In this study, data were available for a period of eight years only.

These limiting factors may have resulted in overestimation or underestimation of the total biomass, rates of change of biomass and hence overestimation or underestimation of the sustainable harvesting rates. Nonetheless, the results in this study give a general picture of how the forest is changing and therefore, important for management purpose.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 Introduction

This chapter concludes the analysis and gives recommendations that would be necessary for the sustainability of forest plantation.

5.1. Summary of findings

The importance of forests in improving human welfare is recognized worldwide. Both natural and artificial forests provide basic human needs such as fuel wood, timber, industrial wood and non timber products. They also maintain air, water and soil quality, protect watersheds and contribute to the biological diversity by providing habitat for flora and fauna. To ensure sustainability of these benefits, there is a need to determine and use sustainable levels of harvesting the wood from these forests. In this thesis sustainable harvesting levels will mean harvesting rates that do not exceed the amount of biomass the forest is able to produce through growth. It can be seen that the current harvesting rate which is about $129{,}000\,\mathrm{m}^3$per year on average (an effort of 0.345), is not sustainable and may lead to decrease the total biomass in the forest plantation.

The result of this thesis shows that, to achieve sustainability, at most 38.717% of Teak and 32.435% of Cebrela biomass should be harvested each year. This is appropriate for sustainability purposes because in each case, the proportional harvests (E) are less than the proportional growth rates (r). Any harvest beyond these efforts is unsustainable.

The carrying capacities show that if all harvesting activities were suspended and proper management practices followed, then at their rotation ages, the species would over time; grow to a maximum biomass of about 553,900 cubic meters and 220,400 cubic meters respectively. Taking the total biomass to be the sum of individual steady states,(34,300 cubic meters) this harvest is equivalent to felling about 30 hectares of 30 year old Teak every year and it represents an effort of about 0.0399 . It must be pointed out that these sustainable harvests include wood left in the field in the form of branches and end portions constitutes about 24% of the total harvest. Therefore the realistic sustainable harvest is 76% of the levels suggested in this study.

5.2 Conclusion

Nevertheless, the following major conclusions can be deduced from the results of the study:

- The current harvesting effort of about 0.345 is not sustainable for the section of the Begoro Forest Plantation.
- Harvesting efforts of about 0.0399 appear to be sustainable for the forest plantation.

5.3 Recommendation to Stakeholders Feature Researcher

In view of the above conclusions and to ensure sustainability, we recommend that harvesting should be restricted to stand at rotation and thinning ages and that it should not exceed 3.99%

Apart from the above recommendation, the following should be done to reduce limitations of the future studies on sustainable forest management.

- Progress reports should be compiled by compartments and species.
- Improved data storage techniques such as use of computers should be adopted at the forest plantation and Forestry Department headquarters as opposed to the current hard – copy system which is liable to damage.
- Forest assistants at the forest plantation should be equipped with forest management skills such as data collection and record keeping.
- There is a need to demarcate community use zones in the Begoro Forest Reserve to control and regulate forest resource exploitation by local communities living around the forest. In this way the forest will be conserved, the biodiversity protected and the resources sustainably used.
- Other models such as percentile – based model, a size class model and state space model can be used can be used to sustain forest reserve.
- In the following papers it could be interesting to conduct a study on assessing the sustainability of Timber harvest of natural forest.
- Using simple model to demonstrate limitations of the utility of indices base on ratios of successive harvests as indicators of sustainability.

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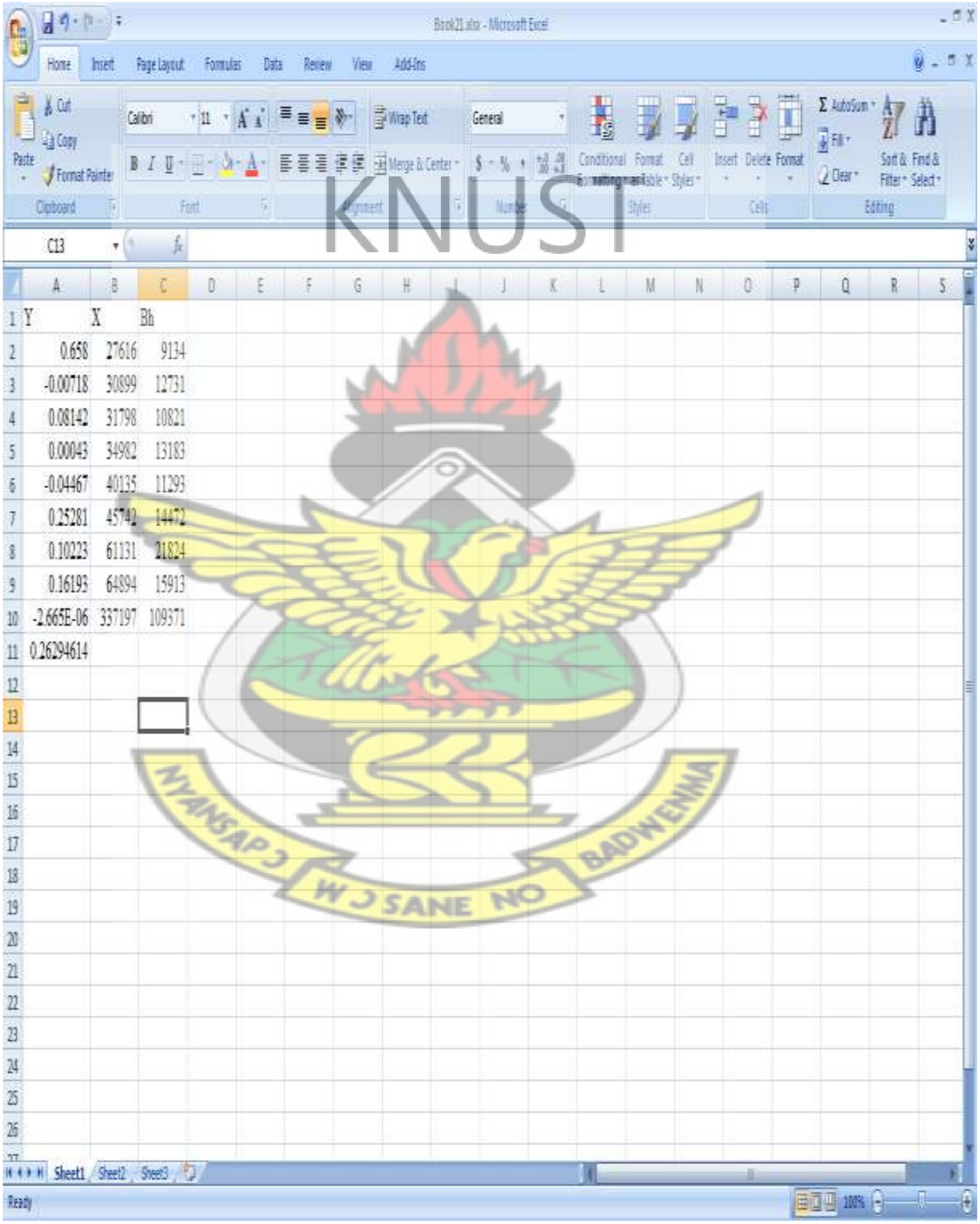
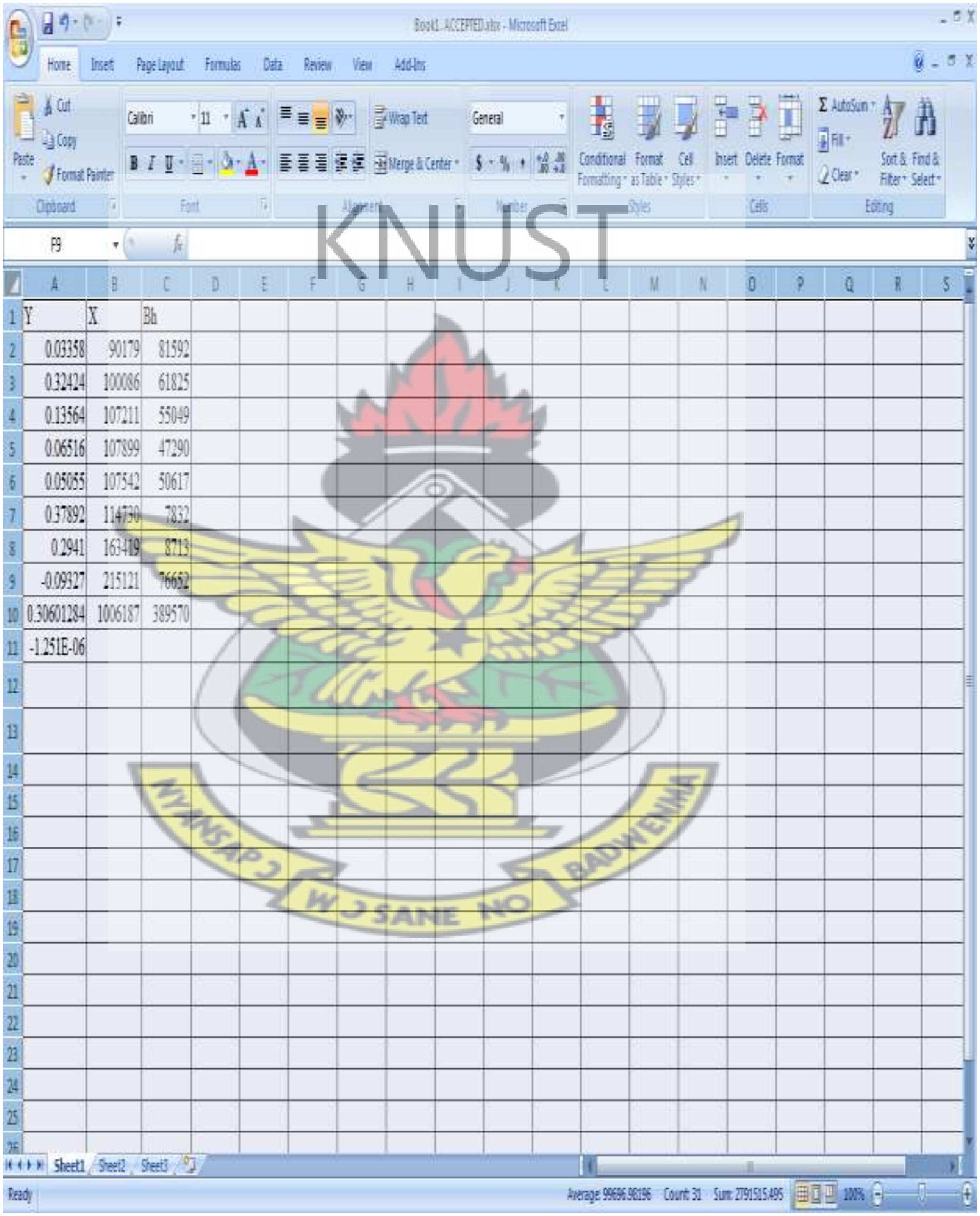
APPENDICES

APPENDIX 1



	A	B	C
1	Y	X	Bh
2	0.658	27616	9134
3	-0.00718	30899	12731
4	0.08142	31798	10821
5	0.00043	34982	13183
6	-0.04467	40135	11293
7	0.25281	45742	14472
8	0.10223	61131	21824
9	0.16193	64894	15913
10	-2.665E-06	337197	109371
11	0.26294614		

APPENDIX 2



Y	X	Bh
0.03358	90179	81592
0.32424	100086	61825
0.13564	107211	55049
0.06516	107899	47290
0.05055	107542	50617
0.37892	114730	7832
0.2941	163419	8713
-0.09327	215121	76652
0.30601284	1006187	389570
-1.251E-06		